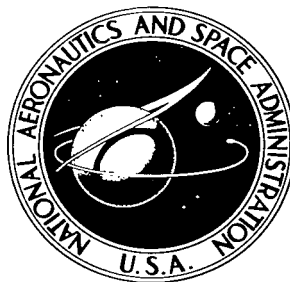


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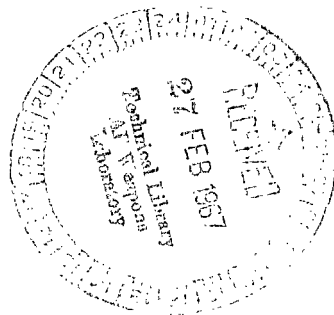


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TECHNIQUE FOR VERIFYING STRUCTURAL INTEGRITY OF FULL-SCALE SEGMENTS OF LAUNCH VEHICLES AT TRANSONIC SPEEDS

by Bernard J. Blaha

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Cleveland, Ohio*





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TECHNIQUE FOR VERIFYING STRUCTURAL INTEGRITY OF FULL-SCALE SEGMENTS OF LAUNCH VEHICLES AT TRANSONIC SPEEDS

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SUMMARY

Wind-tunnel tests of the aeroelastic characteristics of the full-scale flight components of a launch vehicle were conducted at Mach numbers from 0.55 to 2.0. Because of wind-tunnel blockage limitations, only a segment of the vehicle and a corresponding portion of the nose cone could be used to simulate the vehicle configuration. To determine the validity of this technique, static-pressure and terminal-shock data from the model segment were obtained and compared with data from tunnel tests of complete subscale models of the launch vehicle and with flight data. As expected, deviations from axisymmetric flow characteristics were observed. For example, model blockage effects resulted in static pressures ahead of the weather shield step on the full-scale segment 80 percent higher than those on a complete subscale model at Mach 0.9. A knowledge of the flow deviations, however, led to an alteration in the position of the test segment on the model fixture and thus to a better simulation of flight conditions for one series of configurations.

INTRODUCTION

Before the flight of any launch vehicle, extensive ground testing is desirable. A major portion of this testing is conducted in wind tunnels with the use of scale models. In transonic-wind-tunnel testing of large-scale models, interference of the tunnel walls with the model flow field produces an inaccurate simulation of free flight. The models therefore must have small cross sectional areas in order to avoid adverse tunnel flow blockage effects, such as an alteration in the characteristics of the vehicle terminal shock: Model blockage retards the passage of the terminal shock over the model and tends to increase its intensity in proportion to the degree of blockage. Models must also be short to avoid reflected shock waves from the tunnel walls that will alter the flow over the model. In

special cases, however, full-scale tests of the components of a flight vehicle may be desirable. This need for testing is particularly true of aerostructural dynamics studies of flight components because of the difficulty in scaling their structural characteristics for model tests.

The structural loading of many components depends not only on the external pressure distributions produced by the free-stream flow but also upon the differential pressures resulting from the internal pressure in cavities beneath the component. This internal pressure varies in flight in a manner that is frequently a very complex function of the venting arrangements. The uncertainties associated with the internal pressures may be just as significant as those associated with the external pressures at transonic flight speeds. An example occurred in the redesign of the weather shield and the forward seal components of the external insulation panels of the Atlas-Centaur AC-2 and AC-3 vehicles. The apparent structural failure of components in this region at transonic speeds in the flight of the F-1 vehicle (first research and development flight of the Atlas-Centaur combination) created the need for redesign and for ground tests that were as thorough as possible within the limitations of test facilities prior to additional flights. Because the Centaur stage was too large for full-scale tunnel tests, a 60° segment of the portion of the vehicle that was of interest was simulated in the Lewis 8- by 6-Foot Transonic Wind Tunnel; flight components of the redesigned structure were utilized. The approach was to evaluate the effects of the tunnel airstream on the structural integrity of these components (in terms of whether or not the components failed) and to accept the deviations of the flow in the transonic regime arising from tunnel wall interference. Attention was focused entirely on the question of external pressure distributions at transonic Mach numbers, and an assumed schedule of internal pressure was independently controlled as a function of Mach number. The present report examines the validity of testing full-scale flight components in a transonic wind tunnel by evaluating the flow deviations from free flight, particularly in the critical transonic phase of flight. Static-pressure distributions over the surface of the segment were obtained in the Mach number range from 0.55 to 2.0 at zero angle of attack. These results were compared with data obtained from tunnel tests of complete three-dimensional subscale models of the Centaur and with data from the AC-2 flight vehicle.

SYMBOLS

- D reference diameter of Centaur vehicle (120 in.)
M₀ free-stream Mach number
p_x local static pressure at particular point

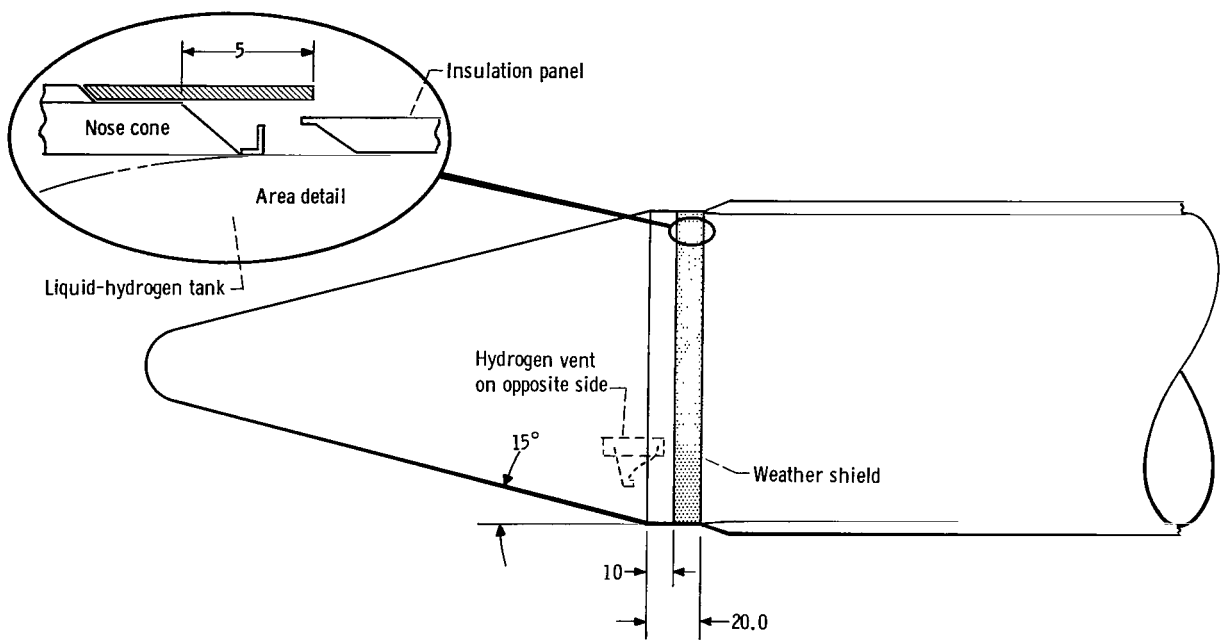
p_0 free-stream static pressure
 q_0 free-stream dynamic pressure
 x distance measured from cone shoulder, in.

APPARATUS AND PROCEDURE

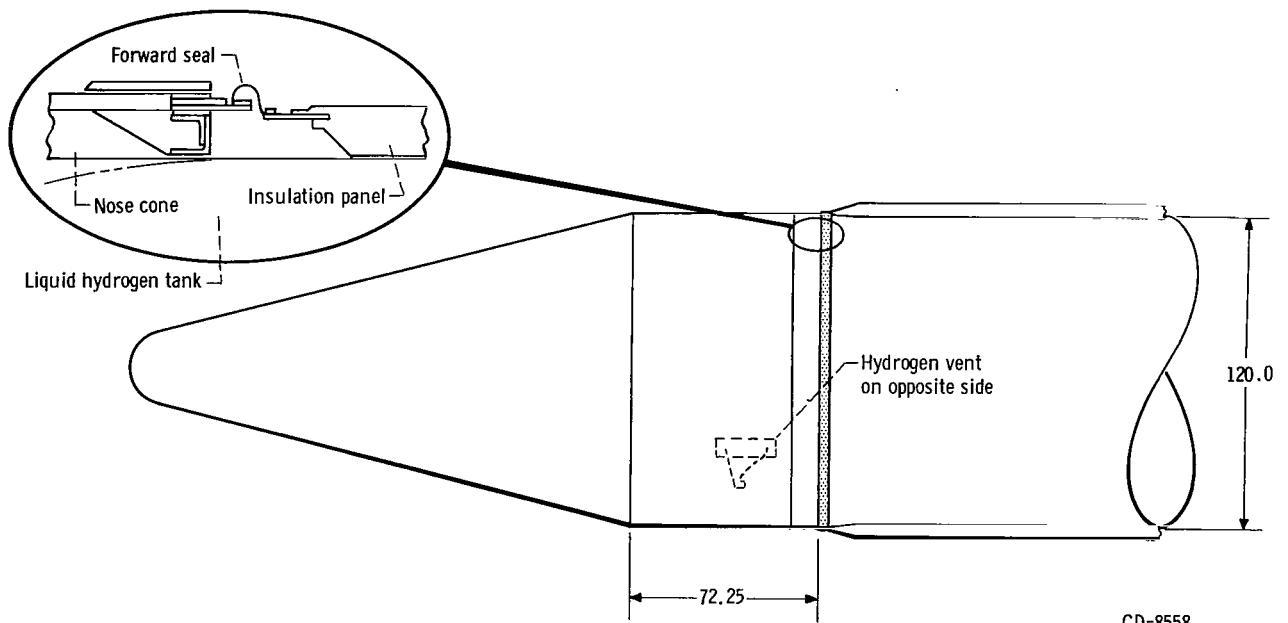
The areas of interest on the two flight vehicles are shown in figure 1. The AC-2 weather shield was mounted 10 inches downstream of the cone shoulder of the Centaur research and development nose fairing. It consisted of a 10-inch-wide by 3/8-inch-thick fiber-glass hoop that enclosed almost 360° of the flight vehicle. A potential problem existed in that the weather shield was cantilevered about 5 inches aft of its mounting on the nose fairing to protect the leading edge of the nonjettisonable insulation panels. Hence, a possibility existed that buffeting from the transonic loads and the terminal shock could result in a structural failure either of the shield itself or of other local components.

The AC-3 forward seal was altered from that used on the AC-2 to permit jettisoning of the panels at high altitudes. It was mounted 72.25 inches downstream of the cone shoulder of the Surveyor nose fairing. The seal was installed to prevent air from flowing under the insulation panels; consequently, the seal had to remain intact until the panels were jettisoned.

Figure 2 shows the model segment in relation to the Centaur vehicle. The model comprised a 60° segment of the full-scale vehicle in the region of the weather shield. It included a portion of the nose cone, the weather-shield section, and 18 inches of simulated insulation panel. The AC-2 weather shield is shown in its proper flight and tunnel test position; however, the AC-3 forward seal was displaced upstream of its flight position for tunnel testing. In order to obtain the proper flow distribution over the test area the model was made as near to the complete three-dimensional vehicle as possible by using the maximum amount of nose fairing or least amount of truncation. The amount of fairing used, however, had to be compatible with the tunnel flow blockage limitations to allow transonic flow to be established and maintained. Two lengths that were used are indicated in figure 2: the projected frontal area of the long fairing A was about 4.7 percent of the tunnel flow area and the blockage of the short fairing B was about 3 percent. To preserve as much of the three-dimensional flow field as possible, especially at the segment edges, a set of flow fences were provided, as shown in figure 2. The heights of the fences for each model length were determined from the theoretical height needed to contain the conical compression field of the nose fairing at Mach 2.



(a) Atlas-Centaur AC-2 research and development nose-cone configuration.



(b) Atlas-Centaur AC-3 Surveyor nose-cone configuration.

Figure 1. - Sketch of areas of interest for the two tests. (Dimensions are in inches.)

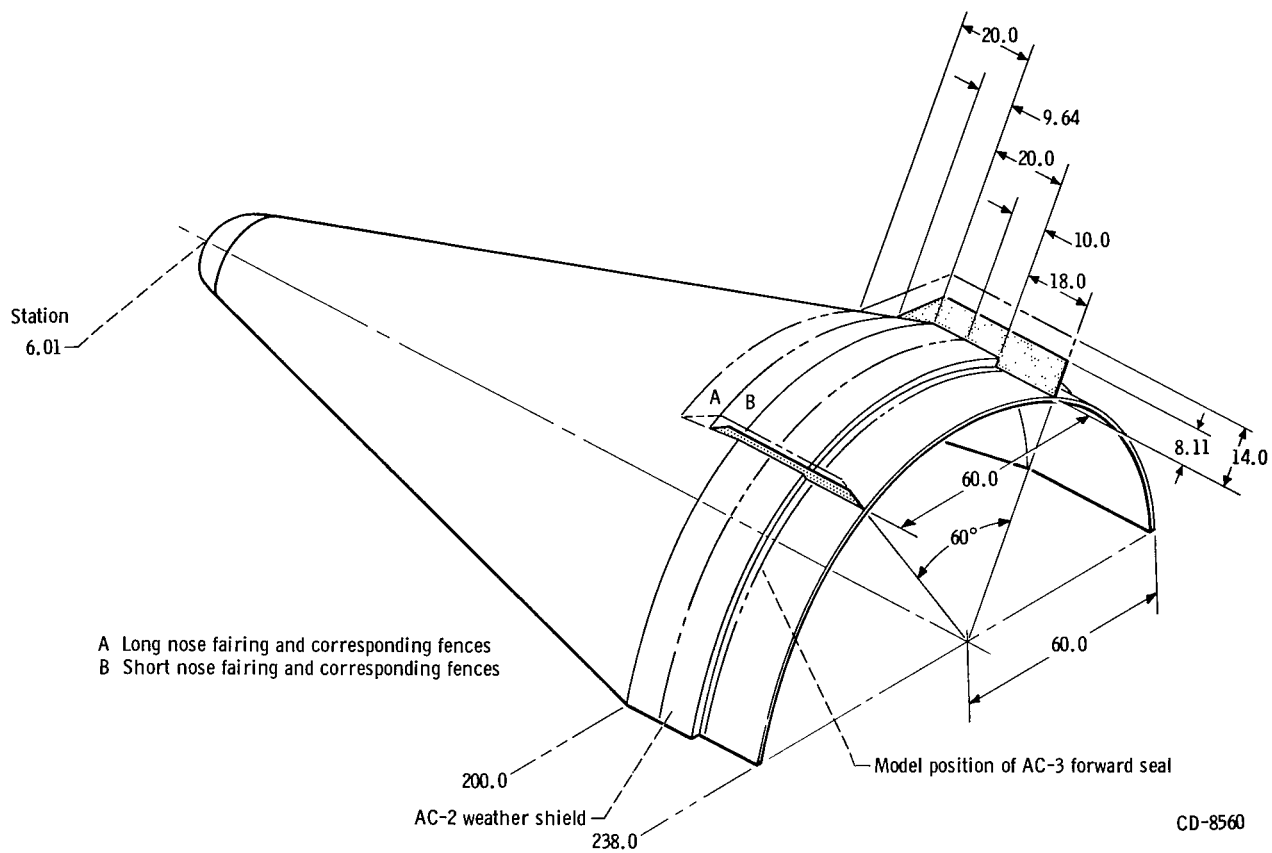
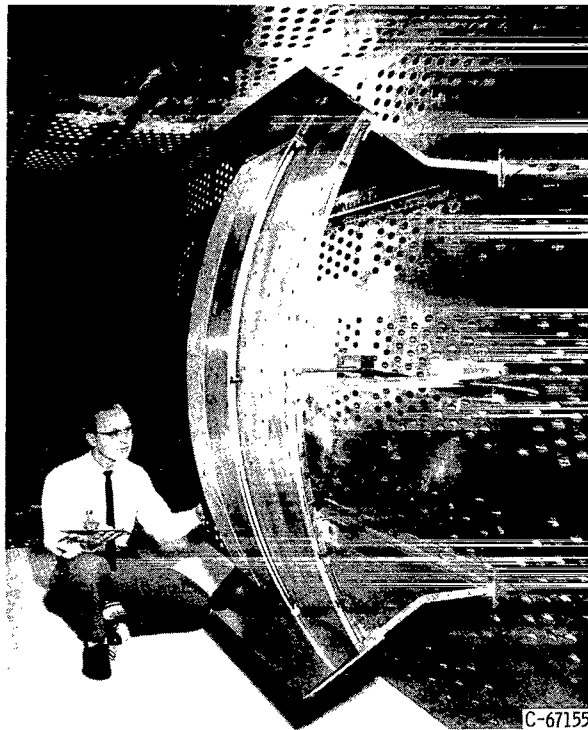
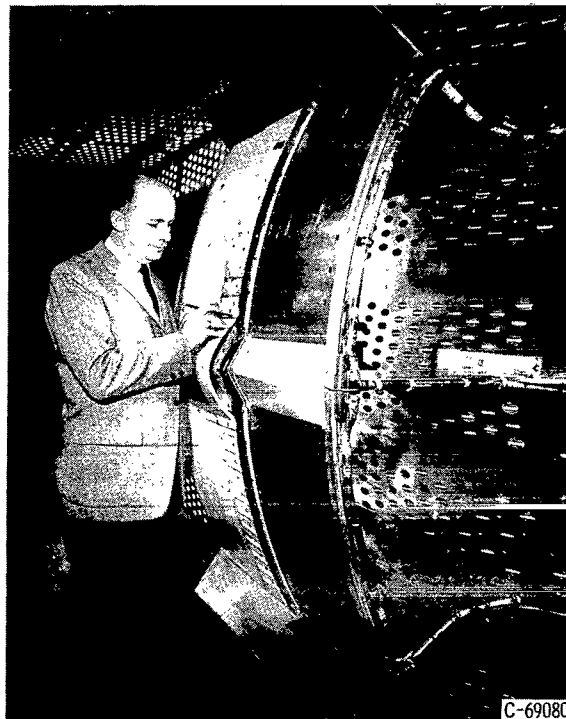


Figure 2. - Sketch of weather-shield model cut from full-scale vehicle (not to scale). (Dimensions are in inches.)



(a) Atlas-Centaur AC-2 weather-shield model.



(b) Atlas-Centaur AC-3 forward-seal model.

Figure 3. - Installation of model in 8- by 6-foot transonic wind tunnel (viewed upstream).

The model segments were mounted to the 8-foot sidewall of the tunnel as shown in figure 3. Tests were conducted with the model at zero incidence to the tunnel flow over a Mach number range from 0.55 to 2.0. Instrumentation and nitrogen supply lines were brought through the base of the model and the model struts. Nitrogen gas was used to simulate bleed flow from under the weather shield and from vent holes on the nose fairing of the AC-2 model (fig. 4(a)). On the AC-3 model, gaseous nitrogen was used to simulate bleed flow from various protuberances (figs. 3(b) and 4(b)) and to control the pressure differential across the seal. The variation of differential seal pressure with Mach number was controlled to simulate that estimated for flight. Liquid nitrogen was used to simulate the thermal environment of the seal on the AC-3 model.

Static pressure instrumentation on the AC-2 weather shield shown in figure 4(a) yielded pressure distributions over the segment. The static pressure taps off the model centerline provided data concerning the circumferential distribution of pressure compared with those on the centerline, and thus indicated the effectiveness of the fences in maintaining a uniform flow field over the model. Also, 14 Schaevitz position transformer

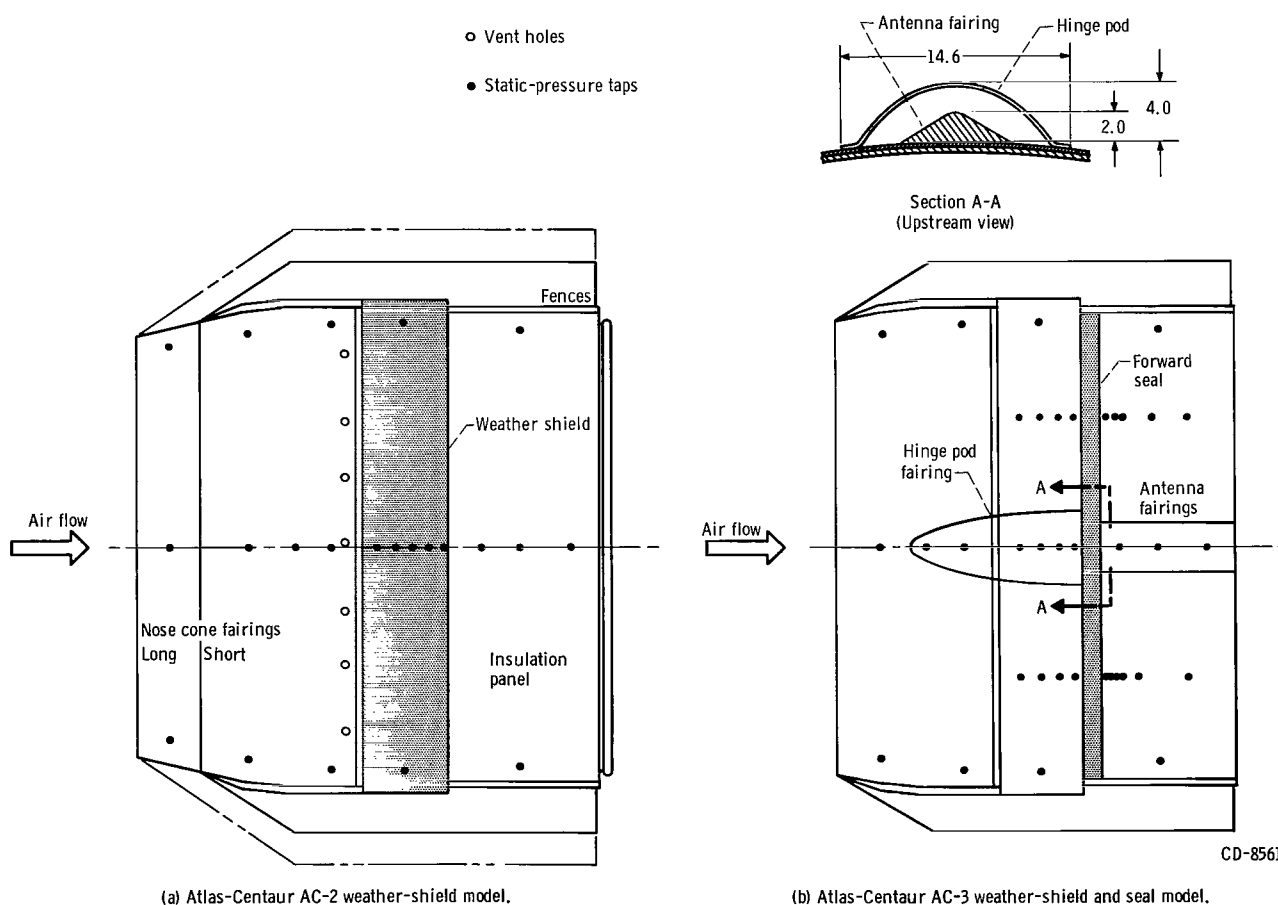


Figure 4. - Sketch of models showing static-pressure instrumentation. (Dimensions are in inches.)

pickups were installed on the cantilevered portion of the test specimen to measure the frequency and amplitude of the weather shield fluctuations. A sketch showing the static-pressure instrumentation on the AC-3 forward-seal model is presented in figure 4(b). The static-pressure taps off the model centerline also yielded the pressure distribution over the smooth (no protuberances) portion of the model, while those on the model centerline provided distribution data over various protuberances that existed on the model. (A typical protuberance is indicated in fig. 4(b).) Both models were so constructed that different 60° segments of the weather shield and the forward seal could be tested. Since each segment was unique in its mounting conditions and contained various local protuberances, a series of tests was required to validate the total 360° of both the AC-2 weather shield and AC-3 forward seal for flight.

During each test, high-speed motion pictures were taken which revealed the nature and propagation of a component failure. The motion pictures revealed the Mach number where component failures originated and also the component movement prior to a failure.

RESULTS AND DISCUSSION

The dynamic pressures of the 8- by 6-foot transonic wind tunnel (fig. 5) were from 50 to 100 percent higher than those of flight over the Mach range tested. From this aspect, the tunnel tests of the flight components were considered to be conservative.

In the following data, pressure distributions from different models in areas that are not influenced by local protuberances are compared. Static-pressure data obtained with

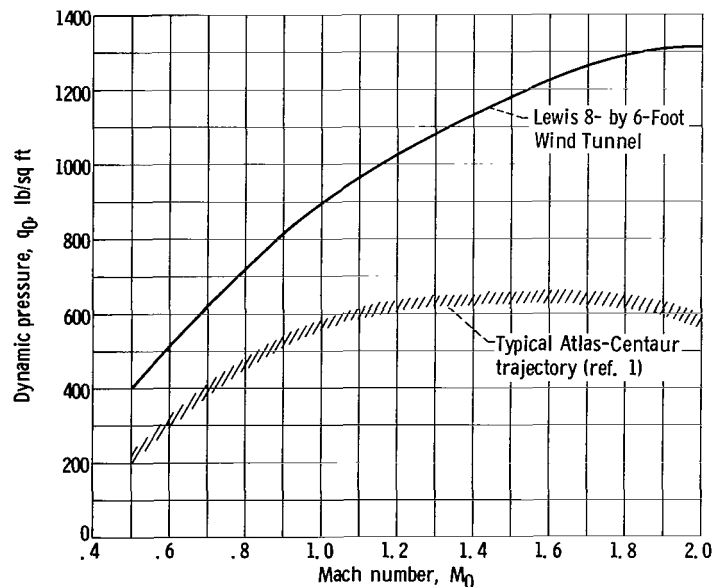


Figure 5. - Comparison of typical Atlas-Centaur flight dynamic pressure with Lewis 8- by 6-Foot Transonic-Wind-Tunnel dynamic pressure.

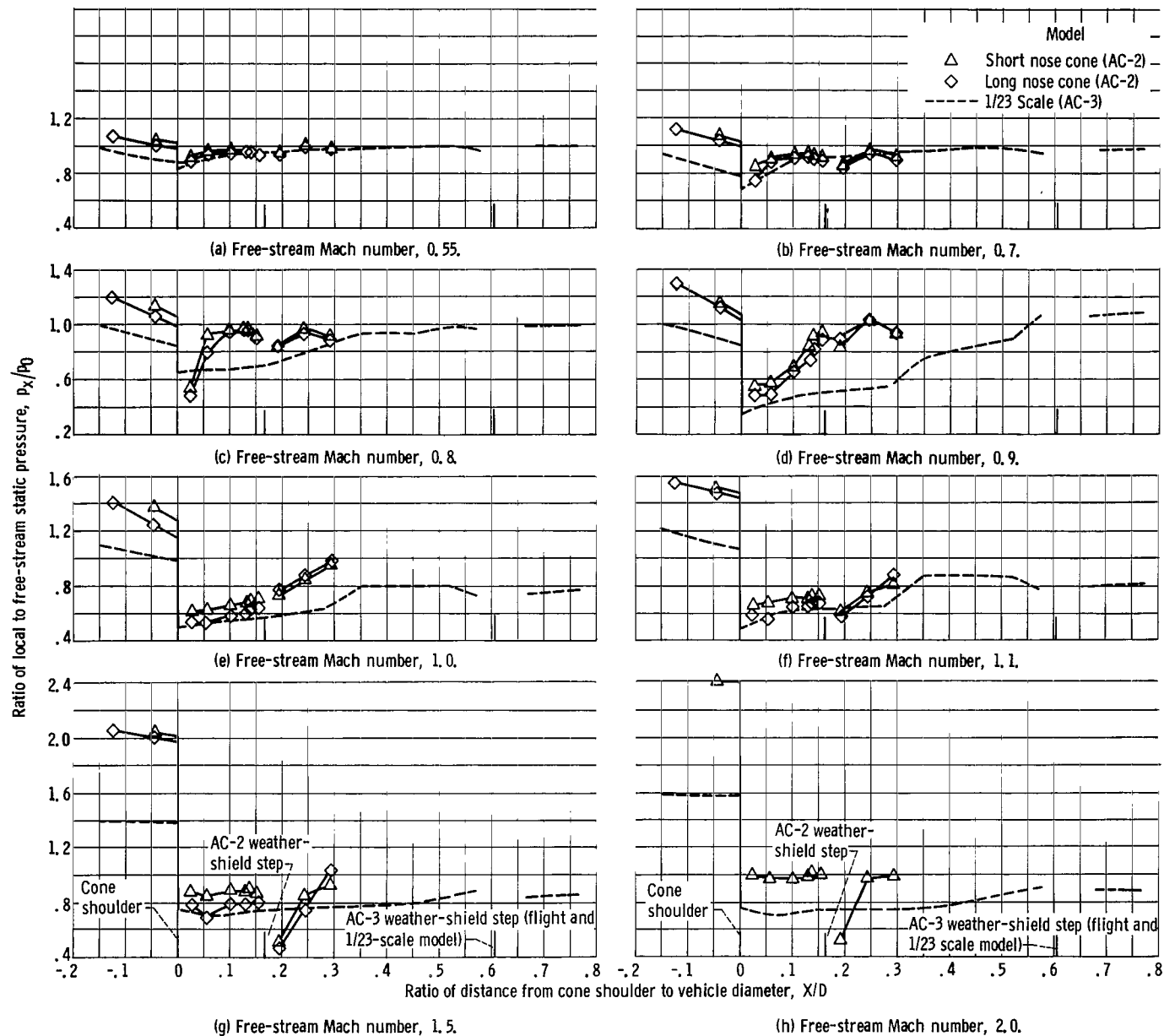


Figure 6. - Comparison of pressure data for Atlas-Centaur AC-2 weather-shield models with that for 1/23-scale AC-3 model.

and without flow fences indicated negligible differences, but the fences were used in the tests of the individual flight components.

Static-pressure-distribution data from the short- and the long-nose-cone AC-2 weather-shield models (fig. 2, p. 5) are presented in figure 6 and are compared with data from a 1/23-scale AC-3 model tested in the same facility. Except for local protuberances, the AC-2 and AC-3 vehicles are the same to a value of X/D of 0.166. Over this portion of the vehicle, the AC-2 weather-shield models experienced higher pressures than the 1/23 scale model (particularly at high supersonic Mach numbers), which indicated a tendency toward two-dimensional flow characteristics. At Mach 2.0 (fig. 6(h)), for example, the pressures aft of the cone shoulder on the AC-2 short-nose model show almost no overexpansion. At lower Mach numbers where the nose cone shock wave was detached, the AC-2 models exhibited overexpansion at the cone shoulder similar to that of the complete three-dimensional model (1/23 scale). These results are generally in accord with those observed for two-dimensional wedges at transonic speeds in references 2 and 3.

As shown in figure 6, the long nose cone produced pressures somewhat closer to the complete three-dimensional 1/23-scale model than the short-nose-cone model. The long-nose model, however, was near the size limit permissible for attaining transonic Mach numbers in the tunnel. Consequently, the short nose cone had to be used in the subsequent testing of the various protuberance effects. For the purposes of this test, the pressures just ahead of the weather shield step are of special interest. A comparison of the pressure data between the short-nose model and the complete 1/23-scale model indicates that the maximum deviations occur at Mach numbers between 0.8 and 1.0. At Mach 0.9, for example, static pressures on the full-scale segment were 80 percent higher than those on the complete subscale model. These large deviations can be attributed to the displacement of the terminal shock on the full-scale weather-shield model resulting from tunnel blockage effects. To illustrate this effect, terminal shock locations aft of the cone shoulder are summarized in figure 7 as a function of Mach number for the AC-2 flight vehicle, various subscale wind-tunnel models of the Centaur, and the full-scale model. These data show that increased blockage retards the passage of the transonic terminal shock over the model. The AC-2 flight data indicate that the shock passed over the weather shield at Mach 0.8. The full-scale-model data obtained with a model blockage of 3 percent show that the terminal shock passed this location at Mach numbers between 0.885 and 0.945, depending on the weather-shield configuration. Unpublished calibration data from the 8- by 6-foot transonic wind tunnel indicate that for larger blockage models (>0.2 percent) wall interference effects enhance the strength of the terminal shock as Mach number is increased between the range of $M_0 \approx 0.87$ to $M_0 \approx 1.05$. The test components were therefore subjected to a stronger shock effect than flight and, consequently, the tests were additionally conservative in this Mach number range.

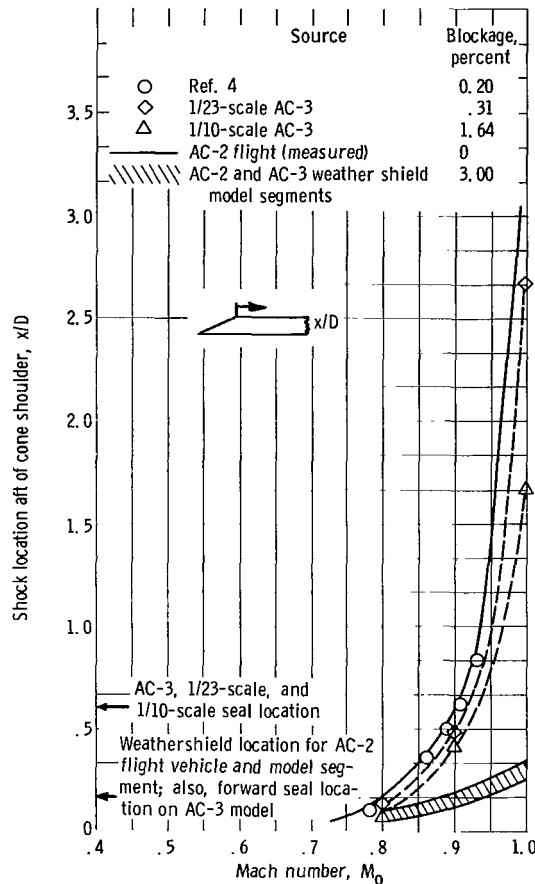


Figure 7. - Position of terminal shock as function of Mach number.

The AC-2 flight data in figure 7 indicate that the terminal shock should pass over the AC-3 forward seal station ($X/D = 0.605$) at a flight Mach number of 0.9. It was reasoned, therefore, that the AC-3 forward seal could be tested in the tunnel at the AC-2 weather-shield position ($X/D = 0.166$) with the result that the terminal shock would pass over the seal at approximately the flight Mach number. This reasoning was also supported by a comparison in figure 6 of the pressure levels near the weather-shield steps of the full-scale AC-2 segment and the 1/23-scale model. The more rapid pressure recovery on the full-scale segment of the AC-2 resulted in pressure levels closely matching those observed near the AC-3 weather-shield step on the 1/23-scale model.

The AC-3 forward seals were tested on the full-scale segment, and the measured pressure distributions over the seal area are presented in figure 8. In this figure, the forward seal model pressures were axially displaced so that the seal station coincided with the flight location to facilitate a comparison with the 1/23-scale data. This comparison indicates that the pressure levels ahead of the weather shield step on the AC-3 model were closer to the complete 1/23-scale model results than were the AC-2 pressures. The maximum deviation again occurred at Mach 0.9; however, the pressures were

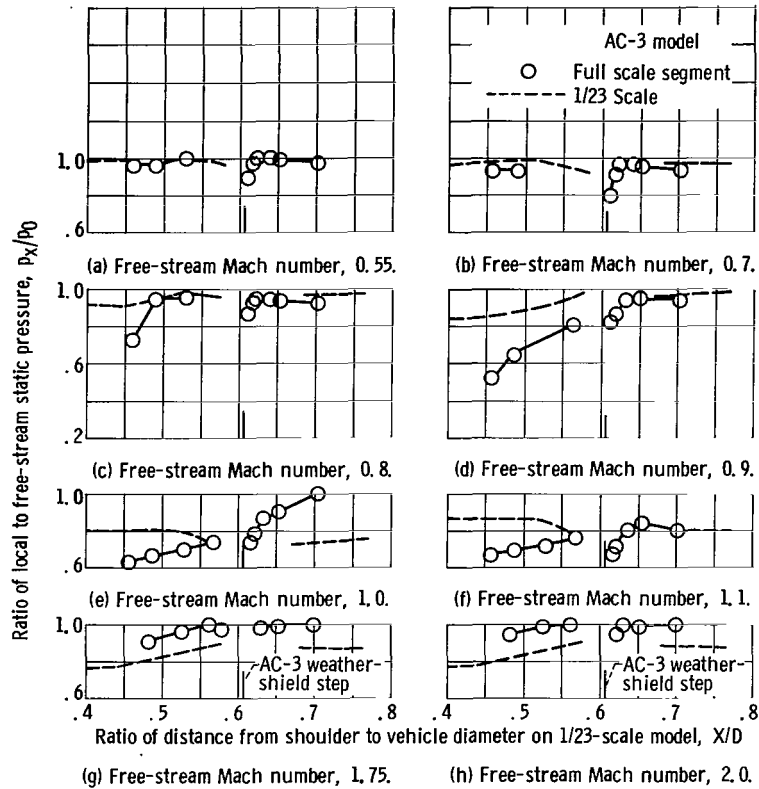


Figure 8. - Comparison of static-pressure data downstream of cone shoulder for full-scale Atlas-Centaur AC-3 model with that for 1/23-scale model.

TABLE I. - TRANSONIC WIND TUNNEL TESTS ON AC-3 WEATHER-SEAL MATERIALS

Seal material	Material thickness, mils	14° Wedge-shaped weather shield	Mach number at initial failure	Total tunnel run time to Mach 2.0, min
Teflon-glass with Teddlar coating, reinforced edges, and one beaded edge	10	None	1.1 to 1.4	154
Teflon	5	None	0.55	136
Teflon-glass	10	Lower half	^a 0.55	100
			^a 0.55	114
		Both halves	None	106
Mylar-Dacron	5	Lower half	^a 0.9	106
Teflon-glass with Teddlar coating and constant cross section	10	None	0.9	110
		Both halves	None	---

^aMaterial failed on side of seal not protected by blunt base weather shield.

25 percent low on the AC-3 segment as compared with 80 percent high on the AC-2 model. Perhaps some of the deviation may be attributed to differences in the details of the terminal shock structure and its interaction with the model protuberances and boundary layer of the two models. Some of the local differences in the flow arose from changes in the local geometry of the full-scale model that could not be duplicated on the 1/23-scale model; for example, the AC-3 full-scale model had a ribbed weather shield that did not exist on the 1/23-scale model.

The test of the individual AC-2 and AC-3 flight components were useful for a conservative evaluation of the design concepts. These tests demonstrated that the AC-2 weather-shield components were capable of withstanding transonic loads even when they were mounted in a loose or free-end manner. The data from 14 Schaevitz position transformers indicated that no flutter or extreme buffeting was experienced by any of the AC-2 test specimens. A summary of the various AC-3 forward-seal material tests, results, and length of tunnel run time are presented in table I. The tunnel run times indicate that the test specimen were subjected to transonic loadings for several minutes, while in flight the exposure would be a matter of seconds. This fact added another conservative factor to the testing. All the seal materials tested on the basic model configuration became

brittle at the liquid-nitrogen temperatures and under the conservative tunnel loads failed before Mach 1.4 was reached in the testing. The high-speed motion pictures revealed that the seal materials experienced extreme buffeting before their eventual failure. Figure 9 shows one of the forward seal failures. The continuous failures of the various materials led to a redesign of the local components in the seal area. The weather shield itself was redesigned as a 14° , 1-inch-high wedge to provide protection from the air-stream (fig. 10), and a new rear retainer was employed that protected the downstream edge of the seal. When tested on one-half the model segment, no failures resulted in the part of the seal protected by the new design, while the unprotected side of the seal experienced additional failures. Figure 11



Figure 9. - Post test picture showing failure of forward seal.

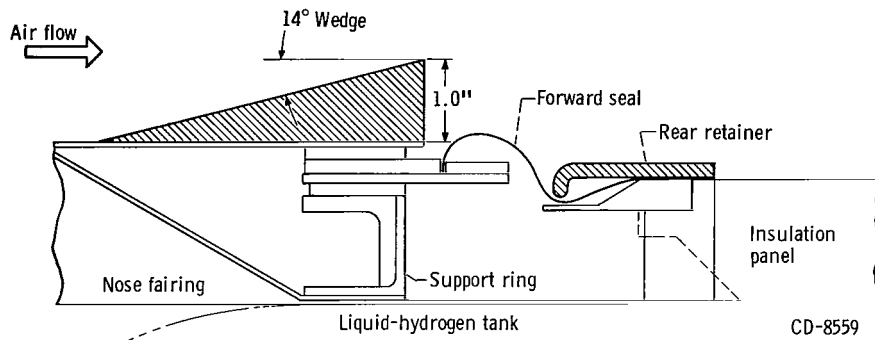


Figure 10. - Sketch showing details of redesigned components in the Atlas-Centaur AC-3 forward seal area (not to scale).



Figure 11. - Post test picture showing that redesigned weathershield component resulted in no seal failure.

presents a post test picture of the forward seal with the redesigned components showing no failure. The local redesign was considered to be qualified for flight and was subsequently used on the AC-3 flight.

SUMMARY OF RESULTS

Wind-tunnel tests of the aeroelastic characteristics of full-scale flight components of a launch vehicle were conducted at Mach numbers from 0.55 to 2.0. Because of wind-tunnel blockage limitations, only a segment of the vehicle and a corresponding portion of the nose cone could be used to simulate the vehicle configuration. To determine the validity of this technique, static-pressure distributions over the surface of the segment were obtained and compared with data obtained from tunnel tests of complete three-dimensional subscale models of the launch vehicle and with flight data. With this model segment, the following results were obtained:

1. As expected, deviations from axisymmetric flow characteristics were observed. The truncated segment of the nose cone produced overexpansion of the flow on the cylindrical surface aft of the cone shoulder similar to that of a complete axisymmetric vehicle at transonic Mach numbers. The pressure level to which the flow was expanded, however, was somewhat higher than with a complete three-dimensional model, and the subsequent recovery to free-stream static pressure occurred more rapidly. The model blockage effects in the wind tunnel delayed the rate at which the terminal shock behind the cone shoulder moved aft over the model surface with increasing Mach number. At supersonic Mach numbers near Mach 2.0 the model pressure distributions approached those of two-dimensional surfaces with an attached bow wave.

2. The pressure distributions for the Atlas-Centaur AC-2 model showed a maximum deviation of 80 percent above those from a complete 1/23-scale model at a Mach number of 0.9. These deviations are attributable to the displacement of the terminal shock due to blockage effects of the model in the tunnel. A knowledge of the pressure deviations and the forward displacement of the terminal shock led to better agreement in the pressure levels on the AC-3 test components: the components were placed closer to the cone shoulder than they would be in flight. The maximum pressure deviation on the AC-3 test model was about 25 percent and again occurred at a Mach number of 0.9. However, in both series of tests, the test components were subjected to a transonic flow regime, although deviations existed in the flow. Since the free-stream dynamic pressure in the tunnel exceeded that of flight by 50 to 100 percent, the testing technique was considered as being a conservative evaluation of the structural adequacy of the flight components.

3. The individual tests produced useful information regarding the detailed design of the flight components and demonstrated the validity of design modifications to withstand the conservative tunnel loads.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, May 18, 1966,
891-05-00-01-22.

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